Continuous frequency tuning with near constant output power in coupled Y-branched terahertz quantum cascade lasers with photonic lattice

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Introduction

Terahertz (THz) quantum cascade lasers (QCLs) are compact unipolar semiconductor sources of radiation in the THz frequency band of the electromagnetic spectrum [1]. THz QCLs are typically processed into a ridge waveguide structure that acts as a Fabry–Pérot cavity supporting multiple lasing frequencies. However, many potential applications of THz QCLs, such as gas spectroscopy and heterodyne radiometry, would benefit from a source that provides fast continuously tunable single mode emission. However, the continuous tuning range that can be achieved electrically through control of the laser current in distributed feedback devices is limited to only ~7.5 GHz [2]. Fast and wideband electrical tuning in monolithic lasers has been demonstrated exploiting the Vernier tuning effect. Such lasers, for e.g. coupled-cavity lasers [3], consist of multiple sections, each of which supports a comb of frequencies; emission is selectively favoured at frequencies at which the lines of individual combs match. Mode selection in such lasers can be accomplished via an 'additive' Vernier effect based on the addition of frequency combs. This latter approach is expected to result in higher side mode suppression of the first side modes compared to multiplicative Vernier effect lasers.

Here, we demonstrate electrically-controlled continuous frequency tuning by exploiting additive Vernier tuning effect in a THz QCL based on a longitudinally-coupled Y-branched waveguide. We report a continuous frequency tuning over ~19 GHz while maintaining an output power of ~4.2–4.8 mW at a heat sink temperature of 50 K.

1. Design and simulation

Our device structure is illustrated schematically in Fig. 1(a), and consists of two double-metal THz QCLs (QCL_1 and QCL_2) that are electrically isolated but optically coupled in the longitudinal direction through a 5-µm-wide air gap. Each QCL consists of four sections: a coupler containing a photonic lattice (PL) structure, which is connected to a 'Y-branch' power amplifier by an S-shaped bend and an impedance-matching tapered section.

In order to achieve the broadest continuous frequency coverage from the coupled device, the PL in QCL_1 was designed to provide a continuous frequency tuning, and the PL in QCL_2 was designed to allow discrete mode hops. Emission in the coupled device was simulated to be at 3.357 THz due to Vernier alignment between modes in QCL_1 and QCL_2 [Fig. 1(b)]. A continuous frequency tuning of ~17 GHz was simulated for the coupled device by exploiting the Stark shift of the gain in the QCL and cavity pulling in the coupled waveguides as the applied electric fields in QCL_1 and QCL_2 were varied heterogeneously [Fig. 1(c)].

2. Experimental results

The emission spectra of fabricated devices were recorded for different combinations of drive current supplied to sections QCL_1 and QCL_2. A continuous tuning over 19 GHz (3.352–3.371 THz), with a side mode suppression ratio >30 dB, was recorded at 50 K [Fig. 1(d)]. Additionally, the output power varies only slightly in the range ~4.2–4.8 mW when the linear shift in emission frequency is recorded, and is due to the constant net gain in the coupled device at these drive conditions.

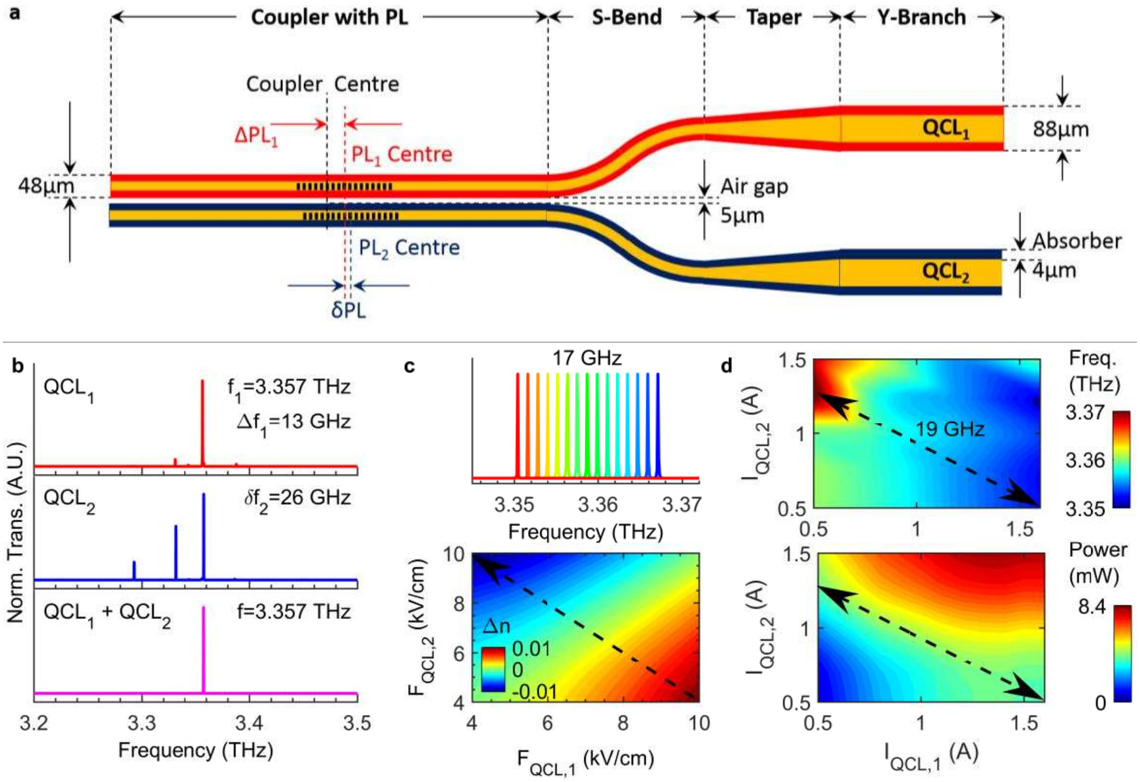

Fig. 1: (a) Illustration of Y-branched coupled THz QCL with PL. (b) Simulated transmission from the device. (c) Simulated continuous tuning due to a change in refractive index arising from Stark shift and cavity pulling. (d) Contour map of experimentally recorded emission frequency and output power as a function of current amplitudes in QCL_1 and QCL_2.

3. Conclusions

In conclusion, fast electrically controlled frequency tuning over 19 GHz (at 50 K) has been demonstrated with near constant output power by exploiting the additive Vernier tuning effect in a THz QCL based on a longitudinally-coupled Y-branched waveguide. These results represent the broadest electrically-controlled continuous frequency tuning reported for a monolithic THz QCL device.

References

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